FLOODS IN A MOUNTAIN STREAM OF THE WESTERN CARPATHIANS (SE POLAND)

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ABSTRACT

The aim of the study is to characterize the parameters of floods (volume, time of concentration, duration and share in the drainage of water from the catchment) shaped by various factors: snowmelt *S*, downpours R_h, continuous rainfall R_c, rainfall with variable intensity over time $R_{(h+c)}$ and mixed (snowmelt-rainfall R+S). The research was carried out in the Bystrzanka stream (13 km^2 catchment area) in the Western Polish Carpathians in the years 1971-2015. The results were obtained on the basis of the limnigram analysis from the water gauge closing the tested catchment. Floods show a high variability of events, duration and size of outflow in subsequent years. The total number of floods in the analyzed period was 408, of which the highest number were of R_h floods (132). Floods occurred on average for 3.6% of the analyzed period and amounted to 21.1% of the outgoing water.

Keywords: floods, discharge, the Bystrzanka stream, Western Carpathians

INTRODUCTION

Floods play a significant role in draining water from a basin. In the case of a mountain stream, the hydrograph often indicates a short period of intense flooding and a multiple increase of discharge. In the Western Polish Carpathians the topography forces thermal zones, that in connection with the land cover (the Beskidian unit cover by forest) causes a delay in the outflow of meltwater from the Beskid part of the basin. This also results in the emergence of secondary climaxes of discharge in the river channel. The floods initiate the transport of clastic material from the basin, which is mainly movement to areas used for agriculture, or other areas of human activity (road investments, strengthening against landslides) [1]. Such above-average hydrological events (e.g floods in 2010) cause transformations in river channels [2],[3].

The purpose of this article is to characterize floods, distinguished on the basis of genetic criteria [4], in the Bystrzanka stream, by defining the following parameters: outflow size, time of concentration, duration and participation in drainage of water from the catchment.

STUDY AREA

The research was carried out in the Bystrzanka catchment (13 km^2 in area) in the Western Polish Carpathians. The catchment is located in the foothills-beskidian area [5], with an elevation from 297-753 m above sea level (Figure 1). The geological substrate of the studied area is the sandstone-shale rocks of the Carpathian Eocene-Cretaceous age, which built the Magura Nappe. Diversification of the relief of the studied area is associated with lithology and tectonics. Beskidian, the western part of the catchment, reaching 753 m above sea level, is characterized by the occurrence of sandstone-shales forms of the Magura area, crossed by thin shales layers [6], having a ridge-forming nature. This area is characterized by higher slopes (up to 35°), occurrence of deep valleys or periodic watercourses and covering the area in mixed or deciduous forest classes. Due to the asymmetrical shape of the catchment, this part of it covers about 30% of the area. The foothills, eastern part of the Bystrzanka catchment is built of shale and sandstone inoceramian layers. The foothills, reaching 450-550 m above sea level, are made of inoceramian formations, which consist of thin- and medium-sized sandstones, which are lined with varying volumes of shale layers, which in some places dominate over sandstones. These forms of relief are broad, slightly sloping (up to 15°), occupied by agriculture fields, which in the last 25 years have been mainly used as grassland.

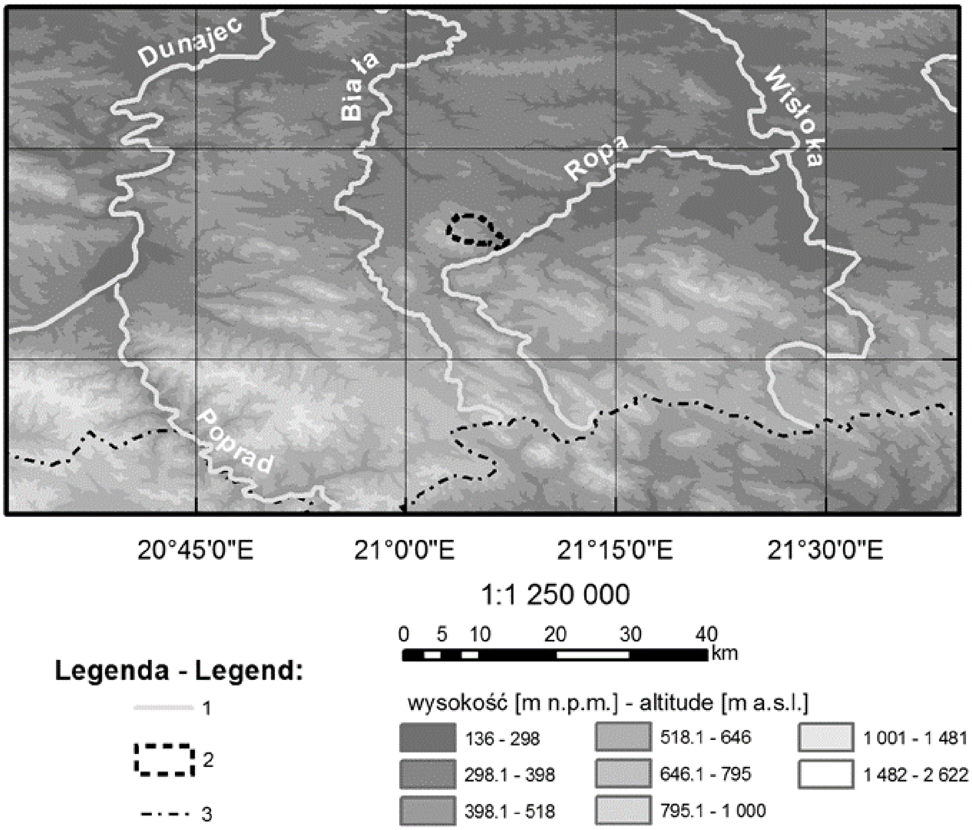

Figure 1. The Bystrzanka catchment: location on the background of terrain relief and network of major rivers of SE Poland
Explanations: 1- major rivers; 2-the Bystrzanka catchment; 3- country boundary

According to the classification of the runoff regimes Parde [7], the outflow from the Bystrzanka catchment is characterized by a simple compound, snow-rain regime, with the outflow dominance in March (mainly due to thaw) and a secondary increase in June (due to precipitation).

METHODS OF RESEARCH

The outflow analysis was carried out on data collected in the water gauge closing the Bystrzanka catchment, directly before its estuary to the Ropa river. In this profile there was continuous registration of the water levels by limnigraph.

The basic criterion for distinguishing floods was the achievements of the so-called discharge threshold (Q_{gr}) [8], calculated on the basis of multiannual characteristic flows:
$Q_{gr} = ½ (NWQ + WSQ)$
NWQ - the lowest of the highest annual discharges
WSQ - the highest of average annual discharges.
The calculated flood flow limit was 0.689 $m^3 s^{-1}$.
The genetic criterion, taking into account the factor causing the spate, was given by Lambor [4] who proposed the following types of floods, which caused by:

- Heavy rainfall [R_h]
  - local storms and torrential rain; occur in small mountain streams and lowland streams with a catchment area smaller than 50 km^2; usually occur in July and August,
  - or rainfalls occurring at atmospheric fronts; floods of this type cover much larger areas, because the range of rains is much wider than torrential rains
- Continuous rainfall [R_c] - long-term precipitation with low intensity; floods of this type cover very large areas and occur from June to September,
- Snowmelt [S] - rapid melting of the snow cover; floods of this type cover large areas; most often occur in March and April, but may also appear in the winter months as a result of a thaw.

In addition, the author of the study distinguished types of floods $R_{(h + c)}$, in periods when heavy rainfall occurred during flood caused by continuous rainfall, causing a significant increase in the discharge, or when the downpour turns into a continuous rainfall, causing high flow in the river. In addition, the author distinguished "thaw-and-rain" floods [R+S], also calling them "mixed", occurring most often in March or early April, when a relatively high daily rainfall (over 10 mm per day) happened simultaneously with the meltwater runoff.

RESULTS

The total number of floods in the period of 45 years discussed was 408 (Fig. 2). The number of rainfall floods [R_h+R_c+$R_{(h + c)}$], which amounted to 293, accounted for 72% of the total number of floods. The dominance of floods is consistent with the spatial distribution of flood types presented by Stachy and Fal [9] in Poland. Among the floods categories highlighted above, most often there were floods caused by heavy rainfall (R_h) in the number of 132, representing 32.4% of the total floods. Snowmelt floods (S) that amounted to 78, accounted for 19.1% of all cases.

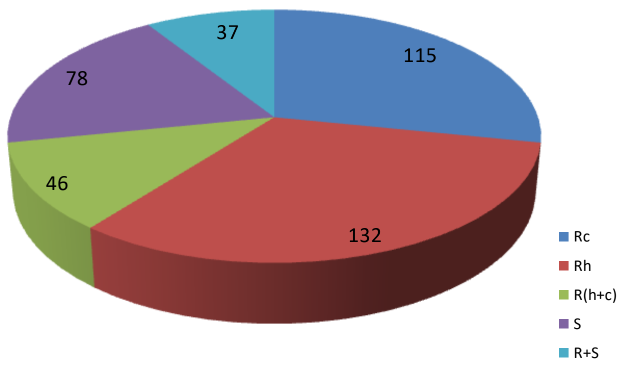

Figure 2. The number of floods distinguished by genetic classification.

The number of floods in particular years was very diverse, from 2 in 2012 to 22 in 2010 and was characterized by high variability from year to year (Figure 3). In these two years there were extreme annual outflow totals, which in 2012 amounted to 85.0 mm and in 2010 - 856.6 mm [11]. Average number of floods was 10.5 per year. This value is higher than the average recorded in the basin of the Ochotnica stream in Gorce Mountain [10].

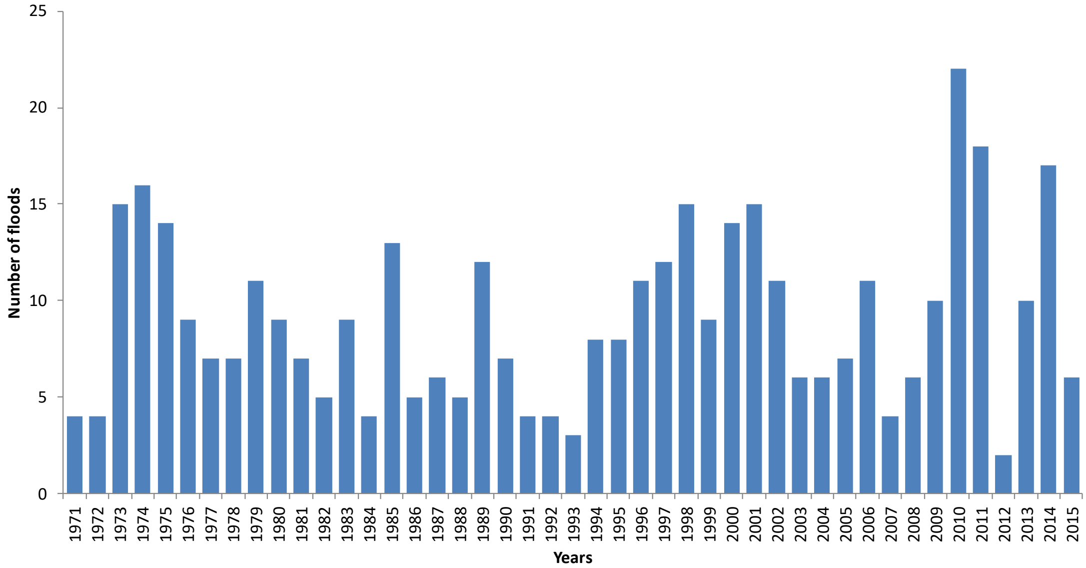

Figure 3. The number of freshets in the Bystrzanka river in the years 1971-2015.

Table 1. Characteristics of individual genetic types of floods; the Bystrzanka stream; 1971-2015

	Genetic types of floods					
	R_c	R_h	$R_{(h+c)}$	S	R+S	**Total**
	Number [-]					
total	115	132	46	78	37	**408**
	Duration [h]					
total	3170	3060	1927	4476	1607	**14239**
average	*27.6*	*23.2*	*41.9*	*57.4*	*43.4*	***34.9***
	Time of concentration [h]					
total	1663	799	861	1765	638	**5726**
average	*14.5*	*6.1*	*18.7*	*22.6*	*17.2*	***15.8***
	Floods runoff [mm]					
total	743.3	1387.8	675.4	617.2	318.0	**3741.7**
average	*6.5*	*10.5*	*14.7*	*7.9*	*8.6*	***9.2***
	Maximum discharge [$m^3 s^{-1}$]					
average	*2.101*	*5.975*	*4.132*	*2.417*	*2.526*	

The floods duration amounted to 14239 hours, representing 3.6% of the duration of the discussed period (Table 1). The longest total duration concerned snowmelt floods (4476 hours), which were also characterized by the longest duration of a single flood event of 57.4 hours and the longest time of concentration - 22.6 hours. The shortest total time concerned “mixed” floods, mainly due to their small number. The shortest duration had a single flood after heavy rainfall 23.2 hours. Floods of this type were also characterized by the shortest average time of concentration, which amounted to 6.1 hours. In the long-term perspective, the average duration of floods during the year was 316 hours, while in individual years it was from 50 hours in 2012 to 845 hours in 1983 (Figure 4).

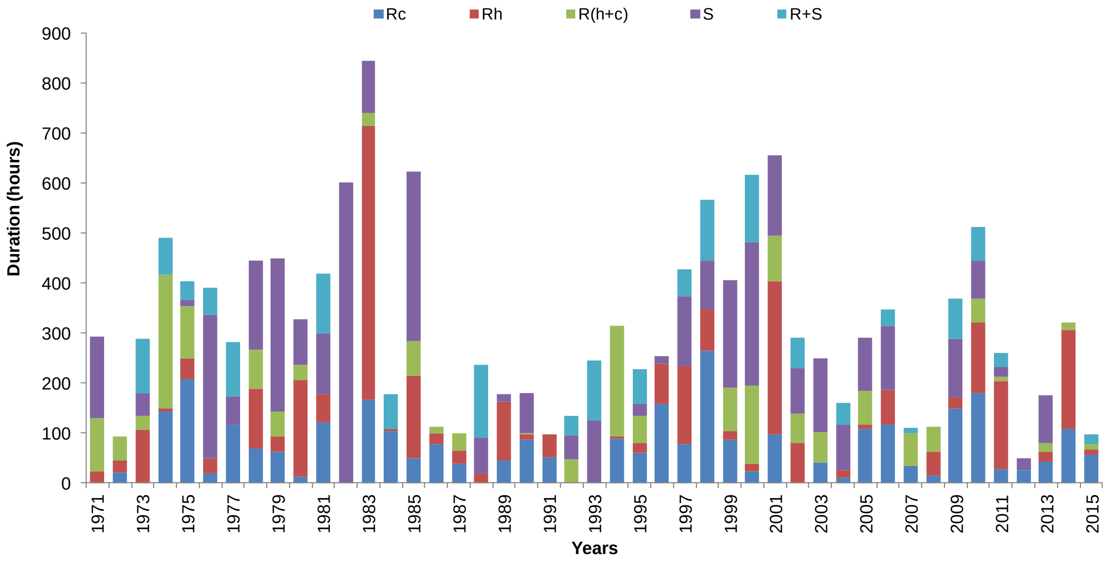

Figure 4. Duration of individual genetic types of floods in the period 1971-2015.

During the research period, there were statistically no significant flood length trends due to the high variability of the number of floods and their duration in subsequent years, which is a typical feature for transitional part of the temperate climatic zone. The analysis of the tendencies indicates a shortening in the duration of floods with a simultaneous increase in the duration of low discharges. Among the distinguished genetic types, only rainfall floods are characterized by an increase in duration, which is correlated with an increased trend in their numbers in subsequent years. Clearly shown is a decresed trend in duration of snowmelt floods, which is a result of decreasing precipitation totals in the form of snow and sublimation from the snow cover. Over the last several years, a rapid increase in air temperature has been observed in the days following the turn of winter into spring, which results in a shorter duration thermally of early spring [12]. The remaining snow cover undergoes the sublimation process, thus the volume of melt water is limited.

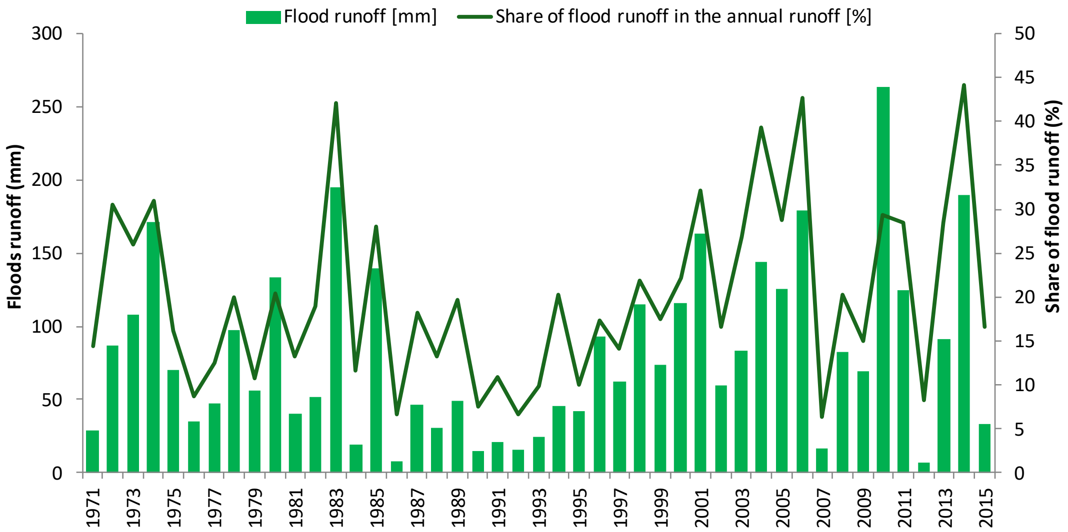

Figure 5. Flood runoff and share of flood runoff in the annual runoff

The flood outflow layer, exceeding Qgr = 0.689 m^3 s^{-1}, amounted to 3741.7 mm, constituting 21.1% of the outflow in the analyzed period. The largest volume of water

was discharged from the Bystrzanka catchment by the R_h floods - 1387.8 mm, whose share was significantly higher compared to the other types of floods and constituted 37% in the outflow of floods. By analyzing the role of a single flood in regards to the amount of outflow, it was found that the $R_{(h+c)}$ floods discharged the largest runoff layer from the catchment (14.7 mm).
In the discussed period between 1971 and 2015, the average annual flood runoff layer was 81.5 mm, showing a variation in the range from 7.0 mm in 2012 to 263.5 mm in 2010 (Figure 5). The annual share of the outflow ranged from 6.3% in 2007 to 44.1% in 2014. Hydrogram models were created on the basis of average parameters of particular flood types concerning: time of concentration, duration and maximum flow (Figure 5).

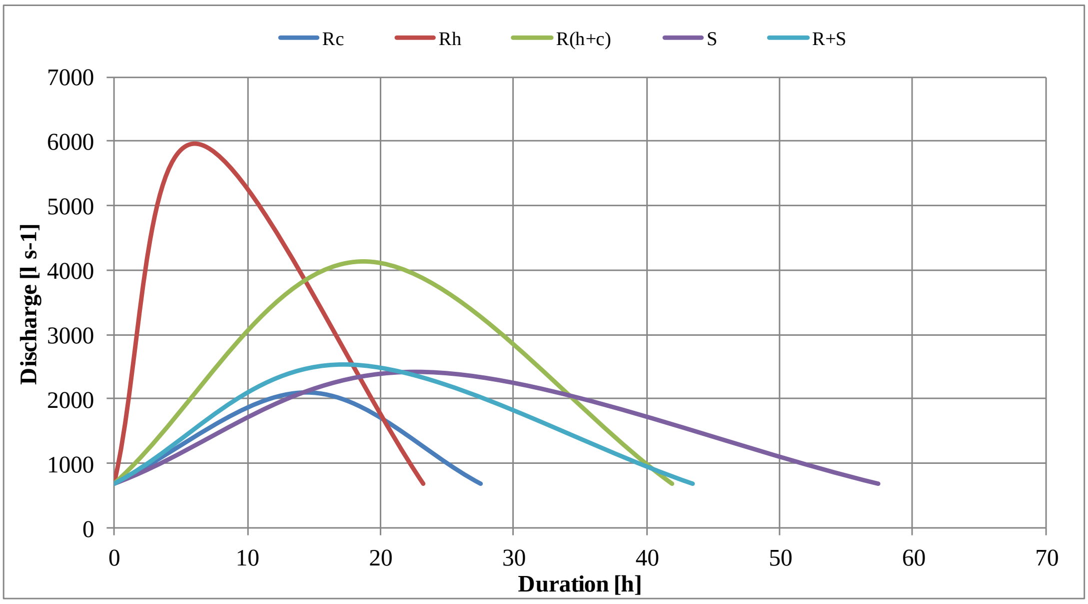

Figure 5. Average hydrograms of genetic flood types in the Bystrzanka

SUMMARY AND CONCLUSIONS

1. Floods that occur in a small mountain catchment in a transitory variety temperate climate zone are the events with a large diversity of number, duration, and genetic type in subsequent years.
2. Among the discussed types of floods, snowmelt floods are characterized by a decreasing tendency of abundance and duration, with a simultaneous increase in the total length of floods.
3. The floods outflow, which on average amounted to 81.5 mm per year, accounted for 21.1% of the normal annual outflow. About 75% of the floods outflow was shaped by rainfall, mainly related to the spring and summer seasons. Therefore, the dominance of the outflow in March is affected by the spring thaw (to a lesser extent) and the above-average discharges which in fact do not meet the floods flow discharge criterion.

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